World Scientific Research Journal (WSRJ) ISSN: 2472-3703
www.wsr-j.org

Analysis of the Influence of Surface Defects on Fatigue Life of Coiled Tubing

Shichao Ma [a], Weihua Sun, Liping Xu, Huajian Wang

College of Mechanical and Electronic Engineering, Shandong University of Science and Technology, Qingdao, China.

[a] sdmasc@foxmail.com

Abstract: In the Complex service environment, the surface of the coiled tubing has different degrees of defects, which can easily lead to the stress concentration on the surface of the tubing and cause premature fatigue failure of the tubing. In order to estimate the fatigue life of coiled tubing more accurately, Ensure the stability and safety of coiled tubing, it is necessary to consider the influence of surface defects on the fatigue life of coiled tubing. The fatigue test of QT800 steel coiled tubing was carried out under the condition of internal pressure 3.4Mpa and bending radius of 1828.8mm by using Full scale fatigue testing machine for coiled tubing. The experimental results show that under the same loading condition and similar geometry, the effect of Impressed defects on fatigue life is less than cut defects. The fatigue life prediction model of coiled tubing with surface defect is obtained by using local strain method. This paper presents a simple treatment for coiled tubing with cut defects and provides theoretical support for field production.

Keywords: coiled tubing; surface defects; fatigue test; local strain method; fatigue life.

1. INTRODUCTION

Compared with conventional thread connecting pipe, coiled tubing has the advantages of quick operation, high efficiency, safety and reliability [1]. It has been widely used in oil and gas field drilling, logging, well completion, oil recovery and other operations [2,3]. During the operation of coiled tubing, the stress state of the coiled tubing is complex. It not only suffers many plastic bending deformation, but also is subjected to internal pressure, so the fatigue life of the coiled tubing is greatly limited [4,5]. At the same time, the service environment of coiled tubing is harsh, and it is easy to cause the volumetric defects such as depression, incision and so on, which cause mechanical damage or corrosion on the coiled tubing surface. The stress concentration in the defect zone will aggravate the crack propagation and lead to premature fatigue failure of coiled tubing [6,7].

The ultra-low cycle fatigue behavior of coiled tubing makes it very important to study its fatigue prediction. A large number of coiled tubing fatigue life prediction models have been developed all over the world. The United States Tipton [8], according to a large number of experimental results for the study of multiaxial low cycle fatigue failure theory, based on the fatigue damage accumulation theory of linear Miner established a life prediction model, found that the coiled tubing internal pressure under the condition of small prediction results are satisfactory. The stress analysis and strength check of the pre-bending coiled tubing were carried out by Professor Li Zifeng [9] of Yanshan University. The stress cycle characteristics of the pre-bending coiled tubing were analyzed in the field operation. On the basis of the fatigue test data under symmetrical cyclic and pulsating cycles, a mathematical model for predicting the fatigue life of pre-bending coiled tubing under arbitrary cyclic conditions is established by using the mathematical method of fitting and interpolation. Wang Youqiang [10] of Qingdao Institute of architectural engineering and Zhang Siwei of China University of Petroleum converted the low cycle fatigue strain life relationship of coiled tubing into the stress life relationship and obtained 1.5 empirical life formula. The probability distribution model of fatigue life of coiled tubing is determined by using fuzzy Bayes theory, and the prediction model of fatigue life and the main factors affecting the fatigue life are obtained. In this study, coiled tubing with surface defects was studied, and the fatigue life model of coiled tubing was established to provide guidance for field construction of coiled tubing.

2. FATIGUE BEHAVIOR AND TESTING MACHINE OF COILED TUBING

The coiled tubing undergoes six bending operations during each service. When into the well, the coiled tubing is pulled out of the roller by an injection head, and the roller hydraulic motor exerts a certain reverse pulling force to straighten the coiled tubing. When the coiled tubing enters the guide frame, it moves along the radius of the guide so that the coiled tubing is bent. After the guide frame goes into the traction chain assembly, the coiled tubing is straightened again. After completion of the operation, the coiled tubing needs to be taken out and coiled again on the cylinder to produce the 3 reverse bending actions. In order to simulate the working condition of coiled tubing, the coiled tubing low cycle fatigue life test device is used for fatigue test. The coiled tubing fatigue testing machine is shown in figure 1.

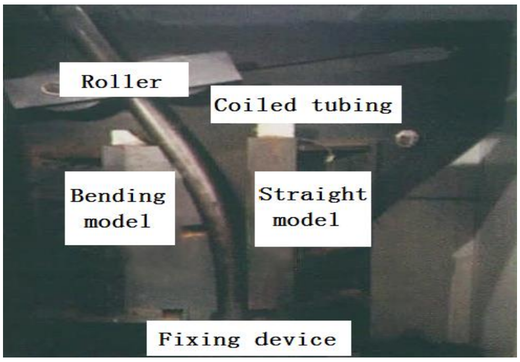


Fig. 1. Coiled tubing fatigue testing machine

The internal pressure of the sample is simulated by injecting pressure to simulate the actual service condition. The internal pressure of the specimen is supplied and maintained by the pneumatic pump. In the steady state, through the drive of the hydraulic-cylinder, the specimen makes reciprocating motion between the two models, determine whether it is close or not by the induction device on the models. The plastic deformation and internal pressure state of the coiled tubing in different service environments can be simulated by changing the size of the bending model and the hydraulic pressure in the specimen. The control system detects that the internal pressure of the specimen is obviously decreased, and the local fracture of the coiled tubing specimen is found, and the fatigue failure of the specimen is confirmed. The fatigue device will stop automatically and the fatigue test will be finished.

3. FATIGUE LIFE TEST OF COILED TUBING

The pipe specimen used in the test is QT800 steel grade coiled tubing. The size of the specimen is 60.3mm * 4mm, and the length of specimen is 1320mm. In the test, the die radius of the fatigue testing machine is 1828.8mm, the die length is 6500mm, the test pressure is 3.4MPa, the stroke is 300mm, and the cycle period is 35s. The test will be divided into cut surface defects of coiled tubing defects (such as scratches and cuts) and Impressed defects (such as pits and gouges), the two kinds of defects of similar geometry under the same load conditions, the specimen bending times to reflect the fatigue life of the coiled tubing, and then comparing the destructive two kinds of defects on the fatigue life of coiled tubing. Two kinds of defects are caused by cut and coining. The geometric size is length * width * depth = 1.5mm*2.5mm*0.8mm.

In order to reduce the experimental error, three tests were carried out for each defect. The average of the three test results is checked by the student t test, and the result is shown in table 1.

Table 1. t-Test: Two-sample assuming Unequal Variances

	Cut	Impressed
Average	270	628.3333
Variance	1497	277.3333
Observation	3	3
Hypothesized mean difference	0	
df	3	
t Stat	-14.7343	
P(T<=t) one-tail	0.000339	
t Critical one-tail	2.353363	
P(T<=t) two-tail	0.000678	
t Critical two-tail	3.182446	

The results of t-test showed that the data of cut defects and impressed defects were statistically significant ($P<0.05$) under the same geometry and loading conditions, that is, the difference between two defects was significant. By comparing the two kinds of defects data, it is obvious that the damage of impressed defects to the fatigue life of coiled tubing is less than cut defects under similar geometry sizes. Using Ansys finite element analysis software, a finite element model of coiled tubing for surface defects is established, and the 3000N concentrated force is applied to the middle of the coiled tubing model. The simulation results are shown in figure 2.

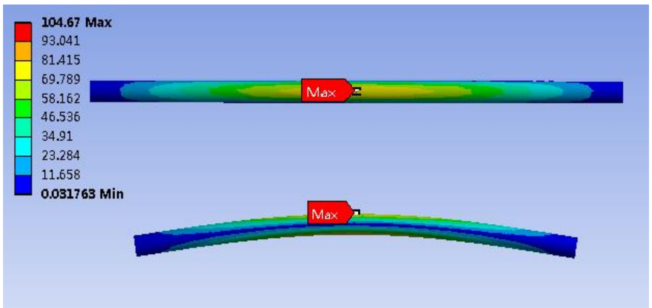


Fig 2. Stress distribution nephogram of the surface defect coiled tubing

The simulation results show that when the coiled tubing is in bending, the axial stress of the coiled tubing with surface defects appears stress concentration, and the maximum stress concentration appears at the defect location, with a maximum value of 104.67MPa. Through experiment comparison, the coiled tubing wall due to cutting caused by the wall thickness is reduced, the local stress in the defects in the working process of concentration is very obvious, which leads to defects in root quickly cracking, the premature fatigue failure of coiled tubing; Impressed defects are caused by local extrusion, also cause the coiled tubing wall thickness decreases, but the compressive stress makes the root defect imprint local hardness increase, to some extent improve the anti-fatigue performance of coiled tubing, delaying the expansion of the root crack defects, thus the emergence of the phenomenon of cut defect damage on the fatigue life of coiled tubing is greater than Impressed defect.

4. FATIGUELIFE PREDICTION OF COILED TUBING

In engineering application, the bending radius of the coiled tubing actually produced than the allowable bending radius was small, and the defects caused by the stress concentration of the coiled tubing into the elastic-plastic state, should be a nonlinear relationship between stress and strain, resulting in plastic strain as the main factors affecting the fatigue life of coiled tubing. In fact, the maximum local strain is the main factor that determines the fatigue life of coiled tubing. Therefore, the local strain method is adopted to predict the fatigue life of the coiled tubing. The fatigue prediction model is as follows: The template is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations.

The defect severity parameter Q [11] is defined to characterize the influence of surface defects on fatigue life.

$$Q = \left[\frac{d}{t} \cdot \frac{w}{x} \cdot \sqrt{\frac{A_p}{A_c}}\right]^{\frac{1}{3}} \tag{1}$$

Where, d, w and x are the defect depth, width and length respectively, t is the tube wall thickness, and Ap and Ac are the project area of defect and crescent area respectively. The greater the defect, the greater the value of Ap, the smaller the value of Ac.

The strain concentration factor Kε is used to characterize the extent of surface defects:

$$K_\varepsilon = \frac{\Delta\varepsilon_q}{\Delta\bar{\varepsilon}} \tag{2}$$

Where, $\Delta\bar{\varepsilon}_q$ is the equivalent amplitude of surface defects and coiled tubing; $\Delta\bar{\varepsilon}$ is the equivalent amplitude of no defect coiled tubing.

The geometrical relationship between the strain concentration factor K_ε and the defect severity parameter Q is obtained from the geometry and stress concentration of the defect.

$$K_\varepsilon = 1 + a \cdot Q^b \tag{3}$$

When the coiled tubing has no surface defects, the surface defect severity parameter Q is 0, and the strain concentration factor is reset to 1. Using the data processing software Origin, two parameters of different defects are obtained, as shown in table 2.

Table 2. Parameters corresponding to the two kinds of defects

	a	b
Impressed defects	2.010	2.638
Cut defects	3.669	2.445

The fatigue life prediction of a QT800 coiled tubing with surface defects can be obtained by the Manson-Coffin [12] formula:

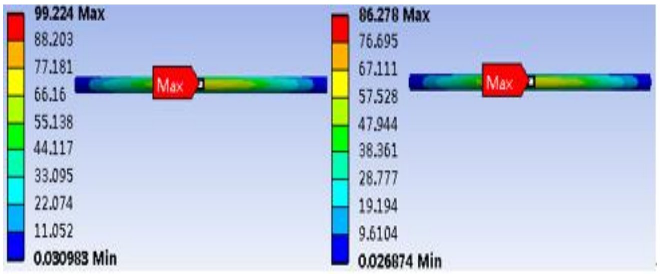
$$\Delta\bar{\varepsilon}_q = \alpha \cdot N_f^{\ \beta} \tag{4}$$

Where, empirical constants are α = 0.105, β = -0.335. When each parameter is added to the Formula (4), the prediction formula can be obtained.

$$N_f = \sqrt[\beta]{1 + a \cdot \left\{\left[\frac{d}{t} \cdot \frac{w}{x} \cdot \sqrt{\frac{A_p}{A_c}}\right]^{\frac{1}{3}}\right\}^b \cdot \frac{\Delta\bar{\varepsilon}}{\alpha}} \tag{5}$$

Where, Nf is the fatigue life of coiled tubing.

The quantitative relationship between the length and width of coiled tubing defects and the fatigue life can be visualized by the prediction model. If you can imagine by changing the length of the defect (reduce defect severity parameter Q) to increase the fatigue life of the coiled tubing, using Ansys finite element analysis software for different defect length of coiled tubing finite element analysis model, the stress concentration is shown in Figure 3.



a. The length of defect is 5.5mm b. The length of defect is 15.5mm

Fig 3. Maximum concentration stress of coiled tubing with different defect length

Analysis results show that the geometrical defects in width and depth is constant, the defect area of the stress concentration along with the increase of the defect length decreases gradually, to some extent alleviate the stress concentration of the coiled tubing fatigue damage and verify the idea to increase the fatigue life of the reduced defect severity parameter prediction Q model. This gives us a simple processing method for cut defects in coiled tubing specifications, under certain circumstances, when the surface defects can damage, by increasing the length of defect along the axial direction to reduce the defect severity parameter Q and increase the fatigue life of coiled tubing.

5. CONCLUSION

(1) The damage of impressed defects to the fatigue life of coiled tubing is less than cut defects under similar geometry sizes. It is found that two kinds of defects both cause the wall thickness of coiled tubing to decrease, but the compressive stress makes the root of impressed defects increased local hardness and improve the anti-fatigue performance, which delayed the cracking defects of local stress caused by root.

(2) Using the local strain method established of coiled tubing with surface defects fatigue life prediction model, the quantitative relationship between the fatigue life of coiled tubing defect length and width were given and provide a theoretical reference for the construction of coiled tubing.

(3) Finite element analysis software ANSYS was used to analyze the stress of coiled tubing with different surface defects of different length. A simple method to deal with the surface defects of coiled tubing is put forward, that is, to increase the fatigue life of coiled tubing by increasing the length of the axial defect in the tube and reducing the defect severity parameter Q.

REFERENCES

[1] He Huiqun, Wang Jinhong, Chang Min, et al. The distribution and growth of Global coild tubing device [J]. petroleum machinery, 2011, 39 (4): 77-79.

[2] Hu Yueting. Horizontal section length optimization method [J]. Acta petrolei Sinica, 2000, 21 (4): 80-86.

[3] Wang Haitao, Li Xiangfang. The coiled tubing technique in underground work in the application and thinking of [J]. oil drilling technology, 2008, 30 (6): 120-124.

[4] Perry K F. Microhole Coiled Tubing Drilling: A Low-Cost Reservoir Access Technology[J]. Journal of Energy Resources Technology, 2007, 131(1):849-860.

[5] Yan Xiangzhen, Deng Weidong, Gao Jinwei, et al. In casing drilling and fatigue reliability of casing string mechanical properties [J]. Acta petrolei Sinica, 2009, 30 (5): 769-773.

[6] Padron T, Luft B H, Kee E, et al. Fatigue Life of Coiled Tubing with External Mechanical Damage[C]// 2007.

[7] Adrichem W P V. Coiled Tubing Failure Statistics Used to Develop Tubing Performance Indicators[J]. Spe Drilling & Completion, 1999, 17(3):173-182.

[8] Tipton S M, Neuharth L G, Sorem J R. Influence of Prior Cycling on Fatigue Damage Caused by in Coiled Tubing[J]. SPE, 2006, 100199.

[9] Li Zifeng, Li Xuejiao, Wang Peng. prebening coiled tubing and fatigue life Prediction [J]. Acta Petrolei Sinica, 2012, 33 (4): 706-710.

[10] Wang Youqiang, Zhang Siwei. Research progress of coiled tubing reliability [J]. petroleum machinery, 1998 (6): 50-53.

[11] Christian A, Tipton S M. Statistical Analysis of Coiled Tubing Fatigue Data[C]// SPE/ICoTA Coiled Tubing & Well Intervention Conference and Exhibition. Society of Petroleum Engineers, 2009.

[12] Chen Daiheng. Fatigue failure and material strength prediction: the concept and application of linear notch mechanics [M]. Tsinghua University press, 2014,135.